Gas in dusty disks around main-sequence stars

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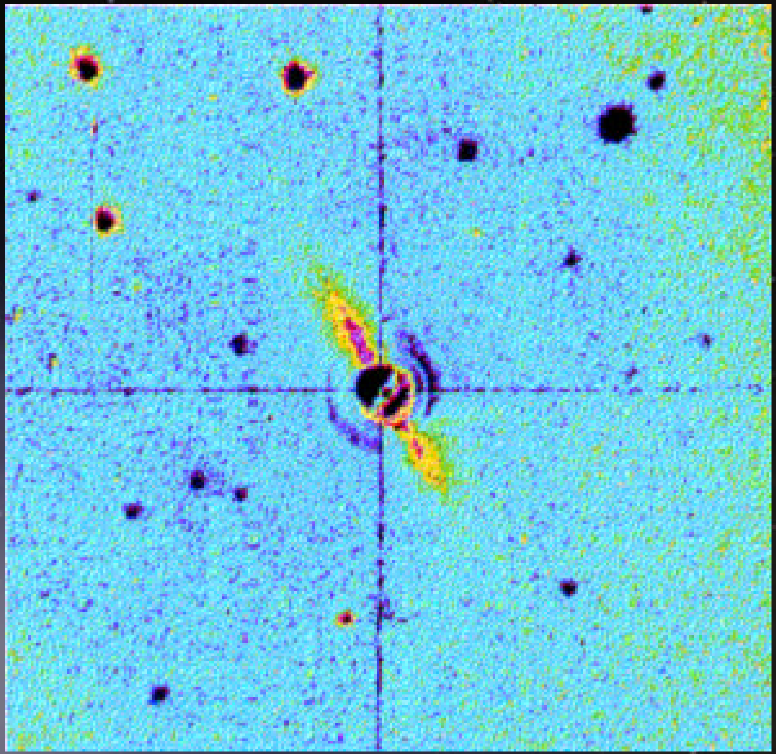
TPF/Darwin conference in San Diego, Alexis Brandeker 2004-07-26

Gas disks?

- Thermal emission from cold gas generally difficult to observe
- Gas/dust relations unreliable
- Gas disk evolution critical for gas giant formation, in particular for the formation mechanisms of hot Jupiters

b Pictoris

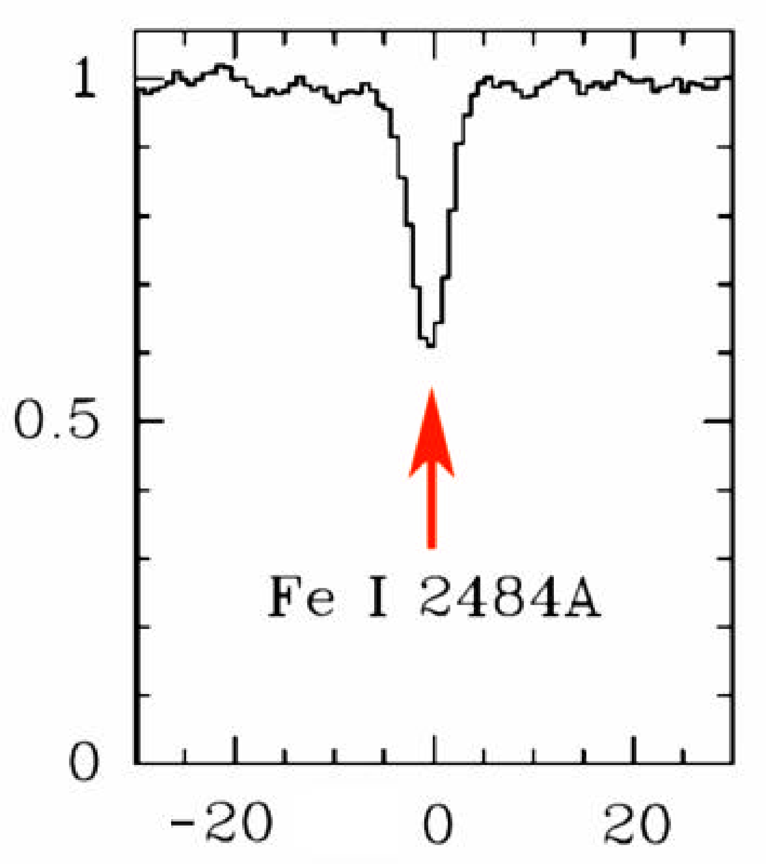


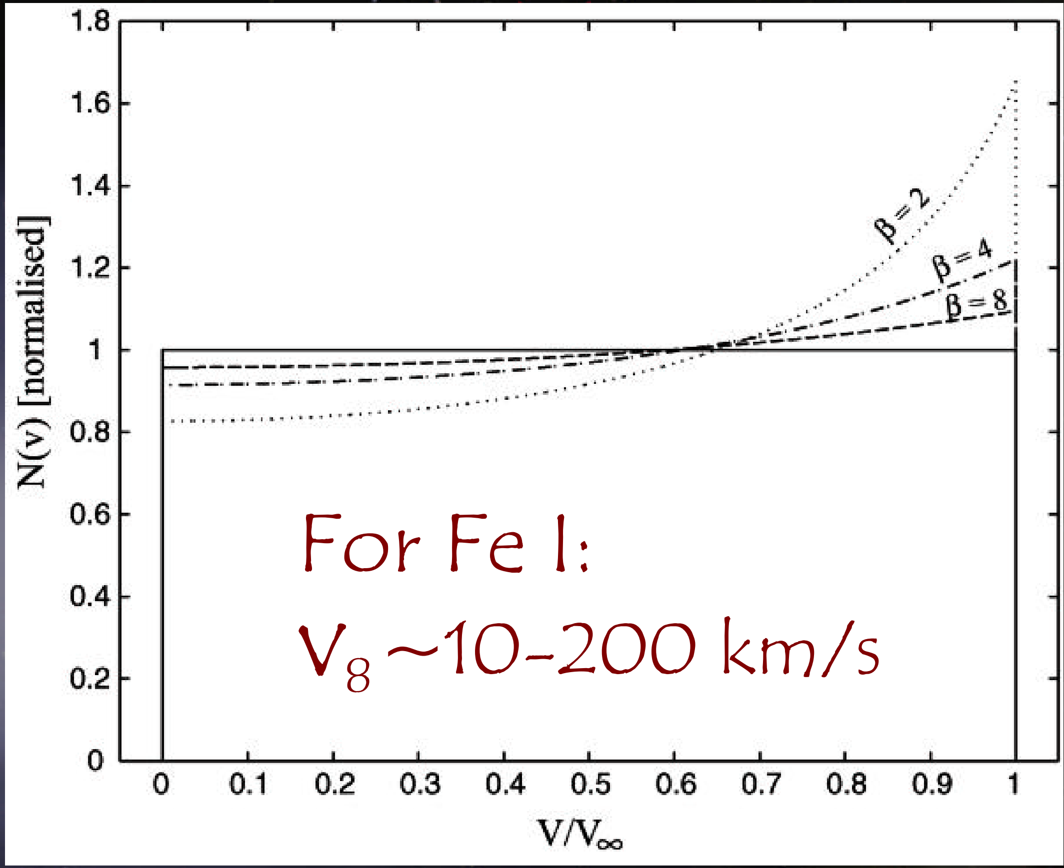
- First spatially resolved circumstellar dust disk (Smith & Terrile 1984)
- Relatively old star having disk, ~20 Myr
- Edge-on ⇒ star seen through disk

The disk gas of b Pic

- Metallic gas discovered in absorption by Slettebak (1975) and Hobbs et al. (1985)
- Substantial radiation pressure (Beust et al. 1989, Lagrange et al. 1998)
- Upper limits on hydrogen:
  $N(HI)$ = "a few" 10^{19} cm^{-2} (Freudling et al. 1995)
  $N(H_2) = 3\times10^{18}$ cm^{-2} (Lecavelier des Etangs et al. 2001)

An unsolved problem





Observed*

Free-ascend solution

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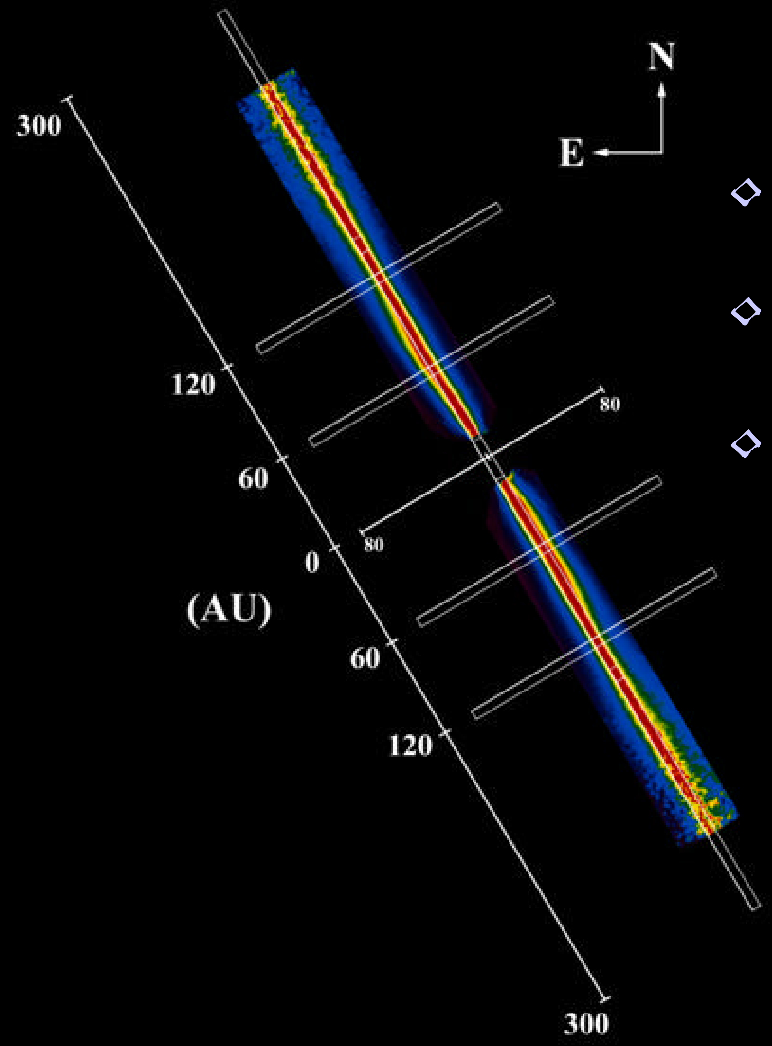
*from Lagrange et al. (1998)

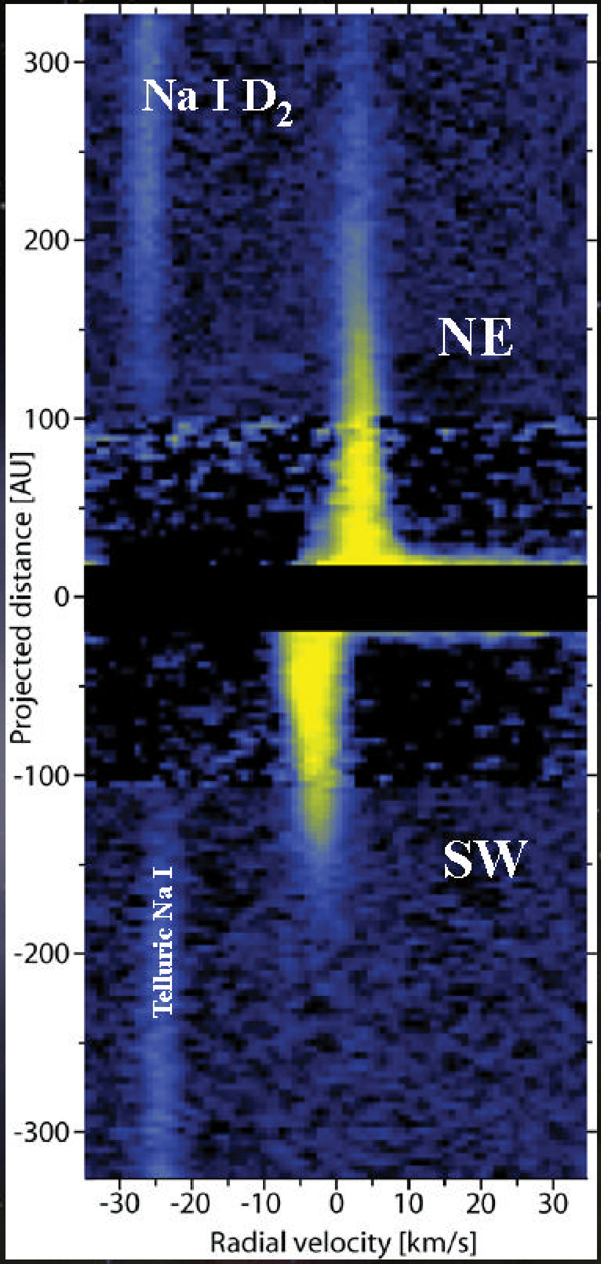
VLT/UVES observations



- VLT Kueyen telescope (8.2m)
- 8 slit positions, seeing < 0.7″
- 3300Å–10400Å at R~100000

Selected results

- 88 lines detected in emission from the β Pictoris disk from Na I, Fe I, Ca II, Ti I, Ti II, Ni I, Ni II, Cr I and Cr II
- Disk emission observed extending to the limits of the observations, from 13 AU out to 323 AU distance from the star, and 77 AU above disk plane



Brandeker, Liseau, Olofsson, & Fridlund (2004)

Modeling

Projection of radial density law:

$$n(r,h) = n_0 \left[\left(\frac{r}{r_0} \right)^{2a} + \left(\frac{r}{r_0} \right)^{2b} \right]^{-\frac{1}{2}} \exp\left[-\left(\frac{h}{\alpha r} \right)^2 \right]$$

All Na I seen in absorption is accounted for by the radial density law derived from emission.

What is braking the gas?

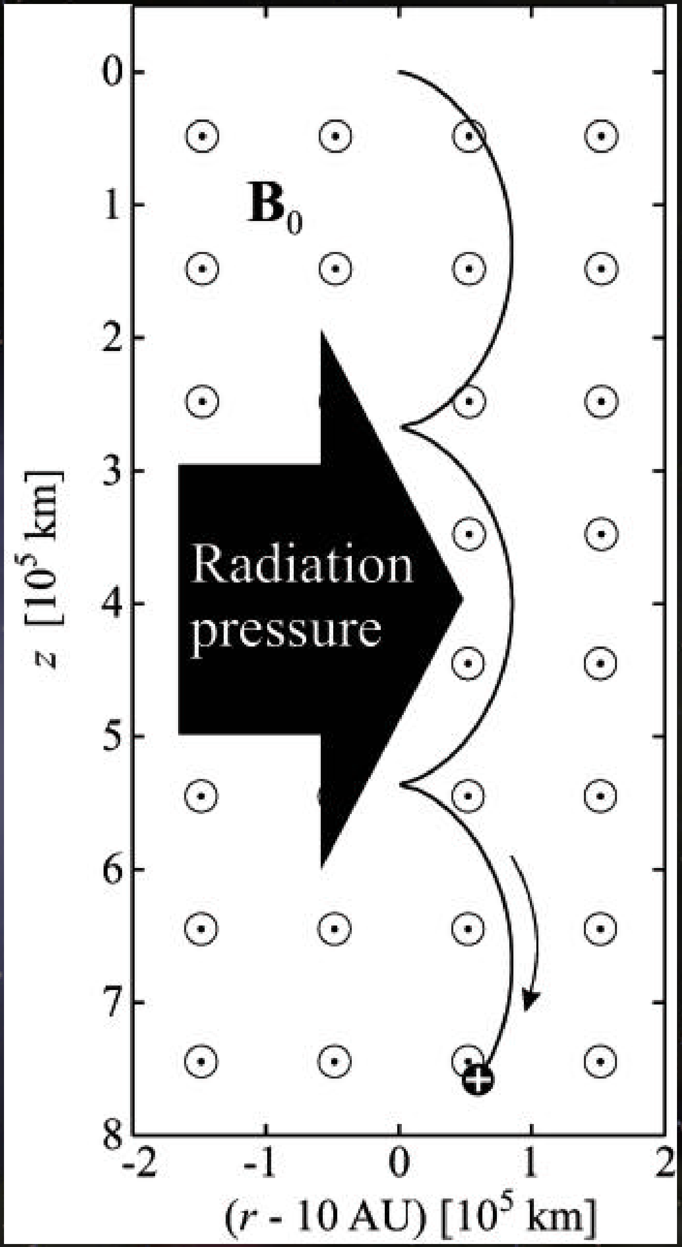
- Possibility 1: The metallic gas is braked by a not-yet detected gas component, not affected by radiation pressure
- Possibility 2: Magnetic forces are at work, braking the metals in an ionised state

Gas friction

- From cosmic abundance: $N(H_{tot}) \sim 10^{19}$ cm^{-2}, insufficient to brake gas
- Required hydrogen column density $N(H_{tot}) \sim 10^{21}$ cm^{-2}, in violation of observational constraints [$N(H_{tot}) = 10^{19}$ cm^{-2}]
- Required oxygen column density is $N(O) \sim 10^{20}$ cm^{-2}

Magnetic force

- Metallic gas largely ionised $\Rightarrow$ sensitive to exceedingly weak magnetic fields (μG)
- Poloidal field does not help, toroidal field required
- Completely ad-hoc



Depletion by diffusion

- Gas particles diffuse out of the β Pic system, driven by radiation pressure
- The diffusion velocity depends on how strongly an ion is affected by RP
- Magnetic braking is sensitive to the gas ionisation, while gas drag is not

Depletion by diffusion

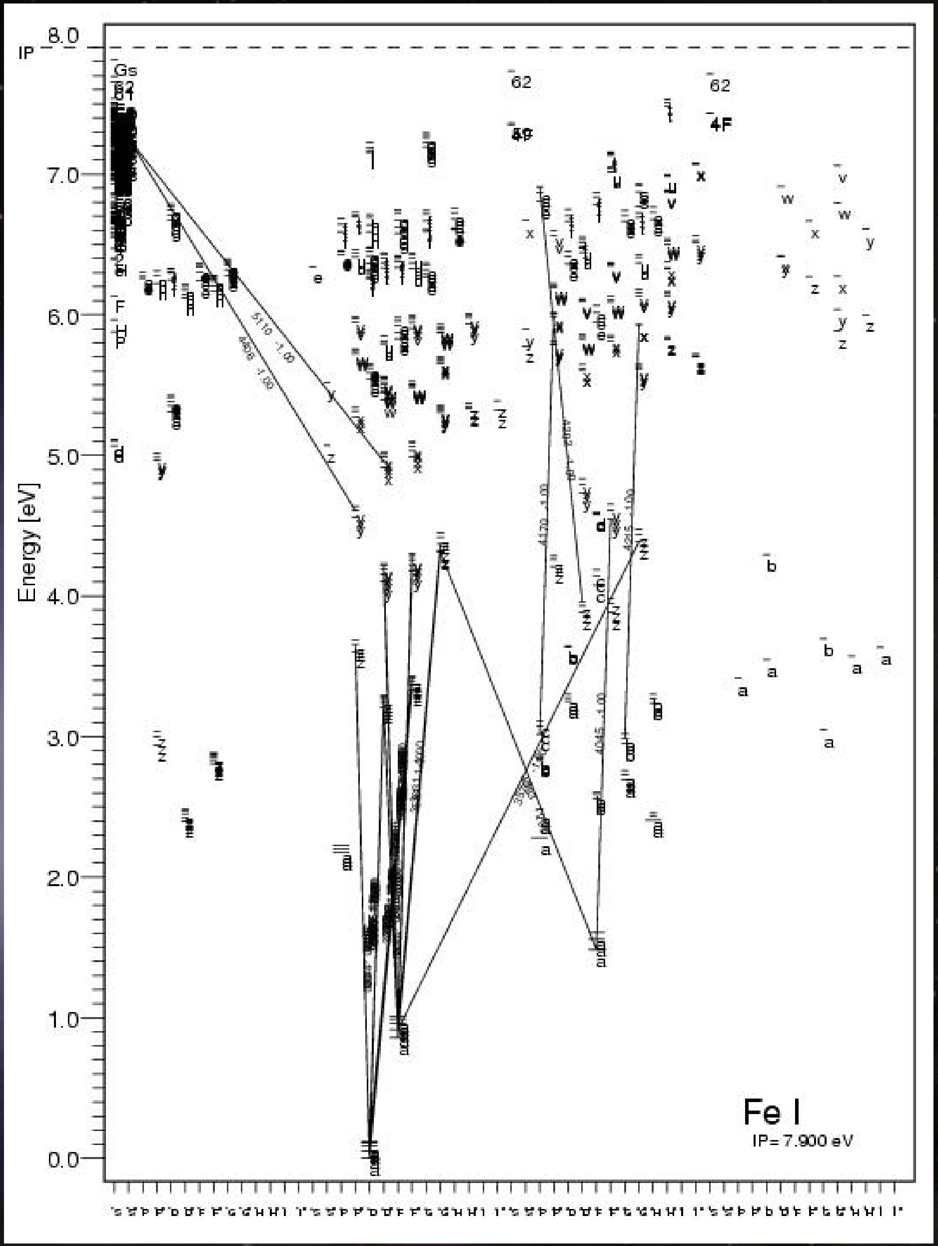
Depletion ratios from radiation pressure

Scenario	d(Fe) / d(Na)	d(Fe) / d(S)
Free ascend	8.1	20
Magnetic brakes	0.7	0.0006
Gas drag	0.65	2.8

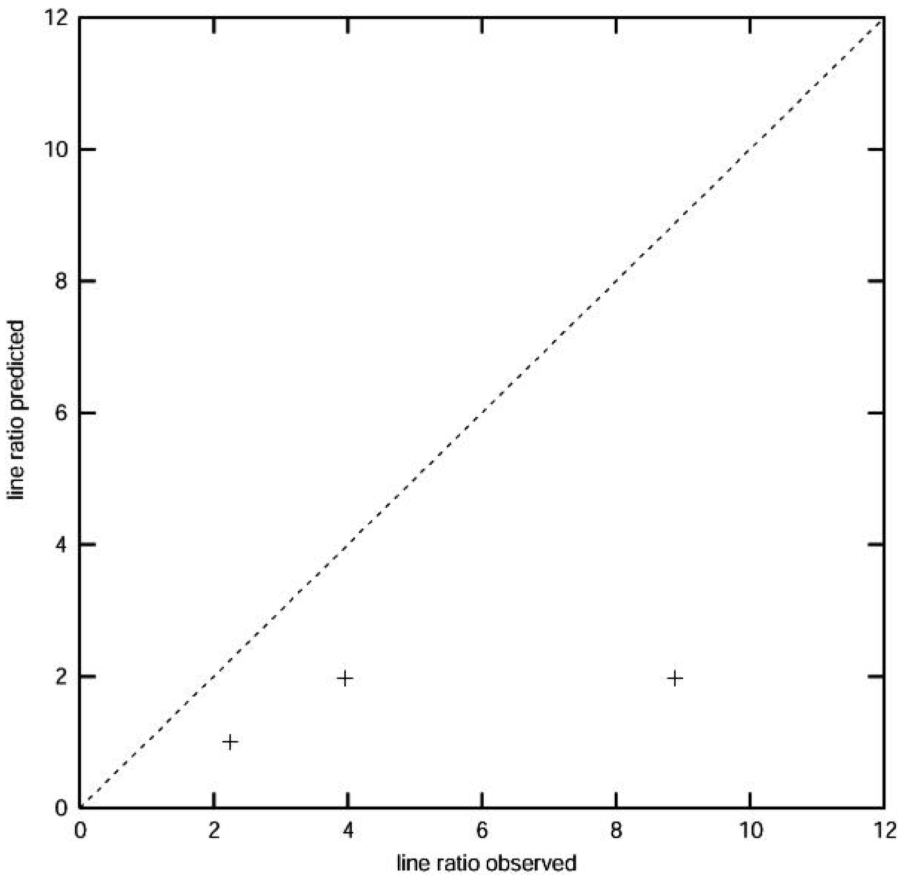
- Rough estimates only – sensitive to detailed ionisation structure. Observed depletion ratio d(Fe)/d(S)~0.3 (Lagrange et al. 1998).

Fe I level population

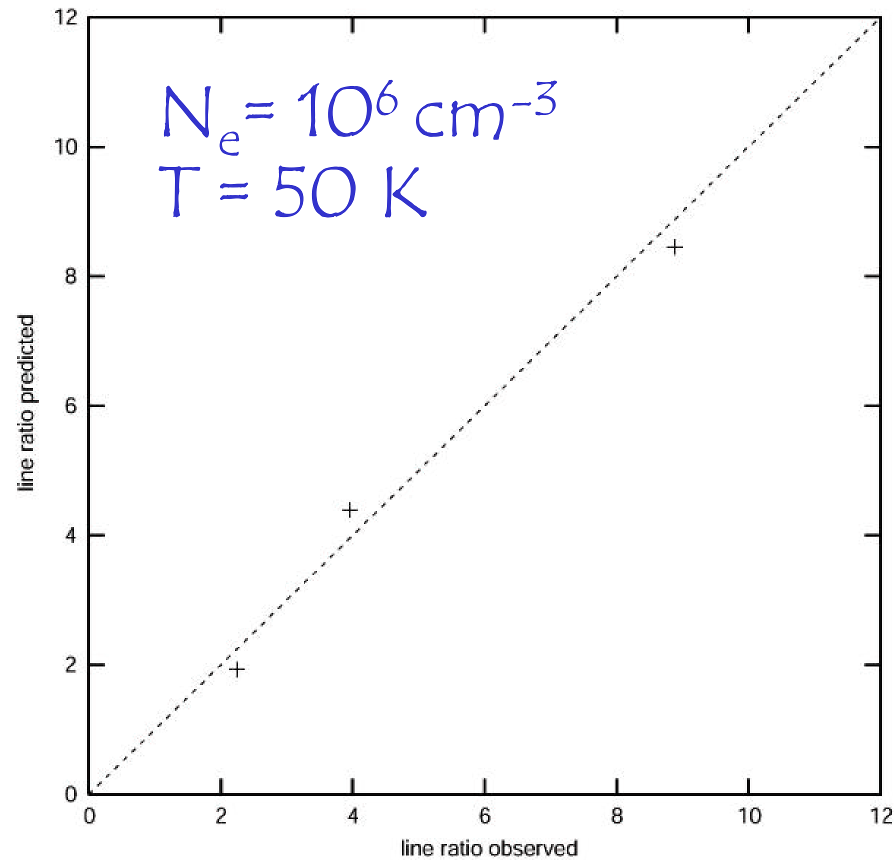
- Model Fe I atom with 842 levels and 9758 line transitions
- Lowest 123 levels coupled by 7140 electron collision cross sections



Fe I level population



Only stellar radiation

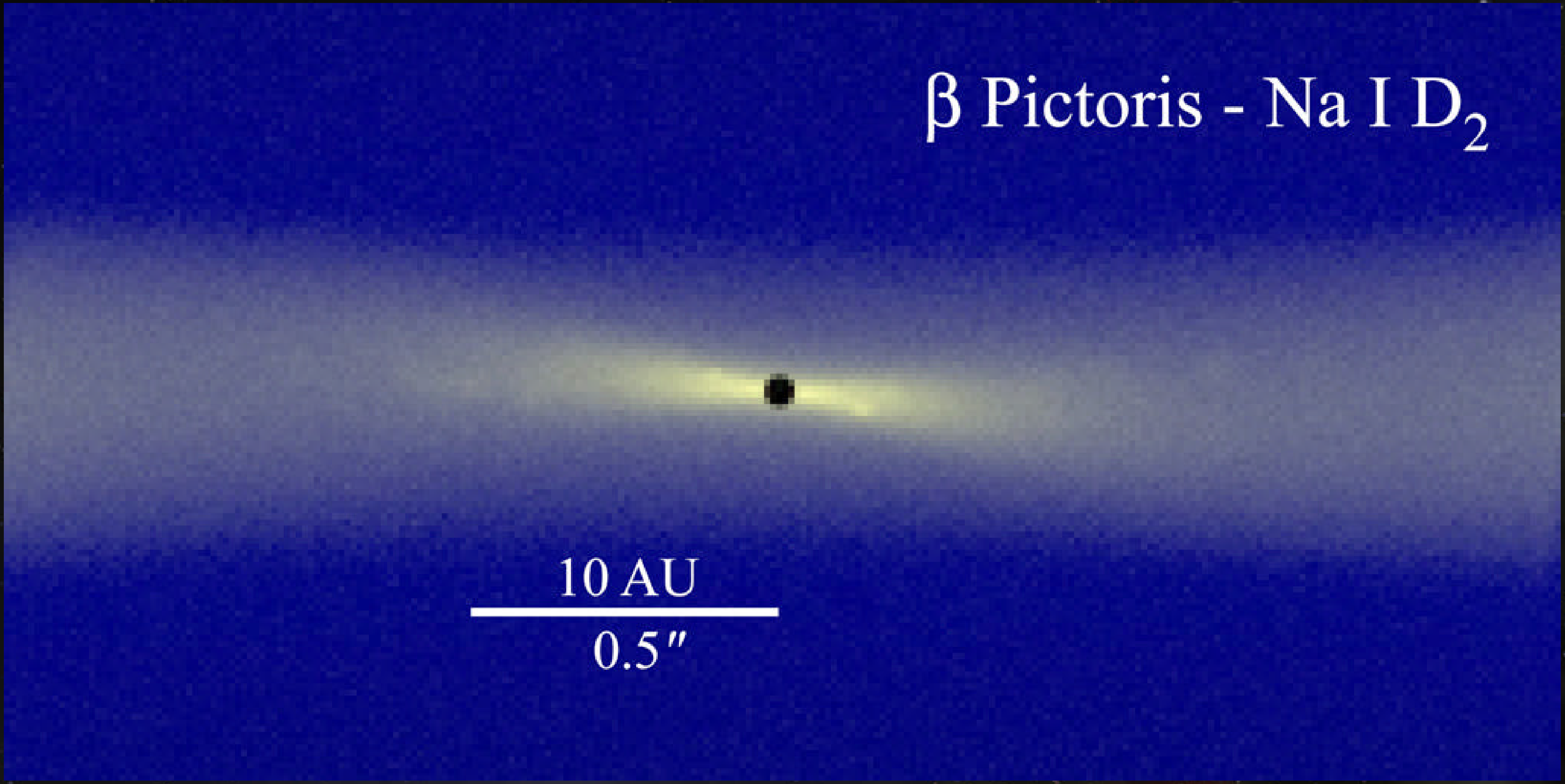


With electron collisions

Future

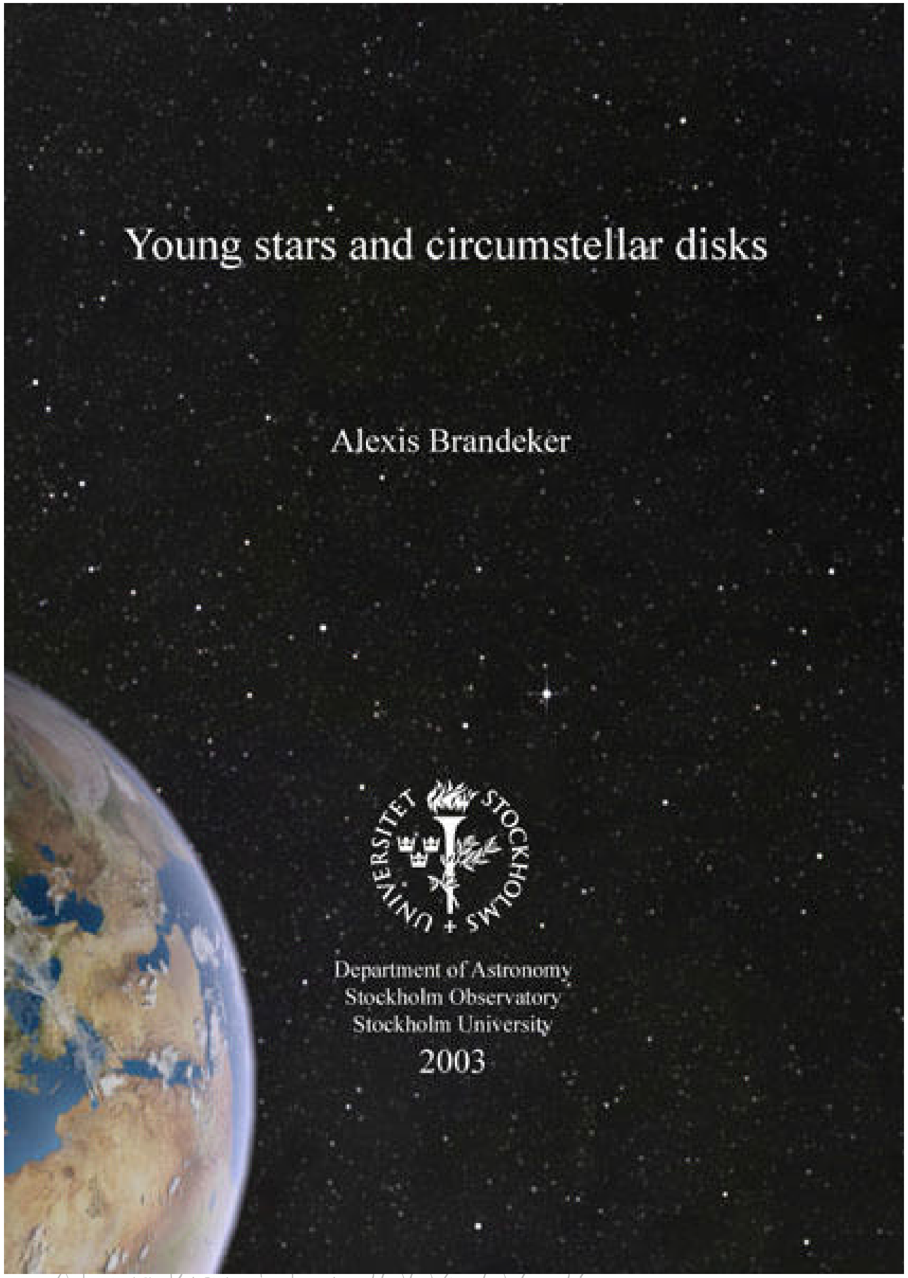
- Current Spitzer GTO β Pic programme (PI Werner) should be capable of detecting $N(H_2) = 5\times10^{20}\mathrm{cm}^{-2}$ (model dependent)
- Recent discovery of β Pic-like edge-on disk AU Microscopii may provide clues to disk gas properties, studying the disk gas in both absorption and emission.
- Observing other accessible dust disks at high spectral and spatial resolution to detect gas in emission will help establish gas/dust relations and the evolution of gas in disks.

TPF-C with a Na I filter

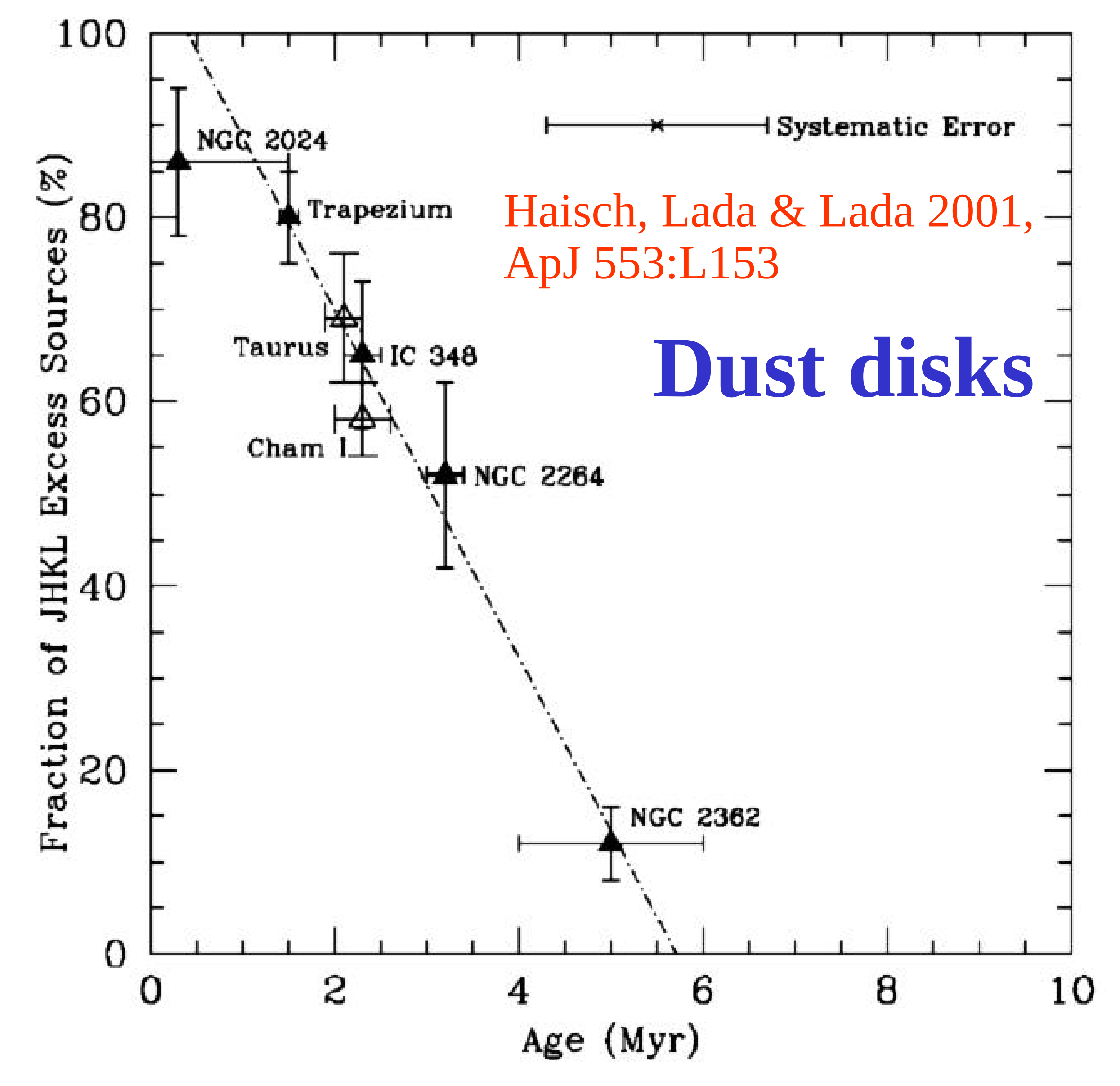


Further details

http://www.astro.su.se/~alexis/thesis.eng.html



Disk lifetimes



Haisch, Lada & Lada 2001, ApJ 553:L153

Dust disks